RESEARCH DEPARTMENT

THE SUBJECTIVE WHITE POINT UNDER THE CONDITION OF NO ADAPTATION

Report No. T-058

(1955/25)

WProctor Wilson

W.N. Sproson, M.A.

(W. Proctor Wilson)

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Section	Title	Page
	SUMMARY	1
1	INTRODUCTION	1
2	BRIEF DESCRIPTION OF THE FOUR EXPERIMENTS	2
	2.1. Subjective White using a Colour-Naming Technique	2
	2.2. 16 mm Kodachrome Test	2
	2.3. 35 mm Technicolor and Eastman Colour Test	2
	2.4. Colour-Balance Tests on Static Colour Transparencies	3
3	COMPARISON OF THE FOUR EXPERIMENTS	4
4	CONCLUSIONS	5
5	REFERENCES	6
6	ACKNOWLEDGMENT	6

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SUMMARY

Four experiments are described in which the white point or colour balance point has been determined. It is shown that while they do not agree in their results, there is a strong correlation when the white point is considered in terms of the average value of the colour temperatures used in a given experiment. The results suggest that various types of colour film will project quite satisfactorily over a wide range of colour temperatures in spite of the manufacturers' efforts to balance the film for a specific type of lighting. Illuminant C* is considered to be appreciably blue for viewing colour pictures under the condition of no adaptation. The optimum white point would appear to have a colour temperature of approximately 5000° K.

1. INTRODUCTION.

In a previous report on Subjective White[1] the optimum colour temperature to simulate white was found to be just over 4000° K when there was no adapting illumination. More recently, tests have been undertaken to determine the optimum colour-balance point** of various motion picture materials such as 16 mm Kodachrome, 35 mm Technicolor, 35 mm Eastman colour. Experiments have also been undertaken to determine the optimum colour temperature for viewing Kodachrome, Ilford colour and 35 mm motion picture transparencies under the condition of no ambient illumination. The purpose of the present report is to describe these experiments and to draw conclusions from the four experiments taken as a whole.

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*An illuminant of colour temperature approximately 6500° K, standardised by the Comité Internationale d'Eclairage.

**If colour film is processed correctly, white is represented by almost clear base. Hence the "white" of a film is the colour temperature of the projector light source and the colour-balance point is equivalent to a determination of the white point.

2. BRIEF DESCRIPTION OF THE FOUR EXPERIMENTS.

2.1. Subjective White using a Colour-Naming Technique.

This constitutes the second method described in a previous report[1] and will only be summarised briefly here. Observers were seated in front of a rear-illuminated opal screen which was illuminated by a projector incorporating colour filters to give nine colours on and near to the black-body locus of the C.I.E. chart. The observers were asked to name the colours using only the six primary and complementary colour names. Every colour combination was shown twice but the order of showing was random. An analysis of the colour namings enabled the white point for each observer to be stated. The self-consistency of namings could also be examined and this was found to be good. The overall results for the twelve observers under a condition of no surround adaptation was 4120° K or 243 microreciprocal degrees (mireds). The range of colour temperatures used in this experiment was 5500° K to 2900° K. The mean of the three values used (worked out on the reciprocal colour temperature scale because this corresponds much more nearly to uniform chromaticity differences than the °K scale) was 3850° K or 259 mireds.

2.2. 16 mm Kodachrome Test.

This test was performed on a 16 mm Kodachrome travel film (Durban Diary) in order to determine the optimum colour temperature for the projection of 16 mm Kodachrome. Eight successive one-minute excerpts from this film were projected with six different colour temperatures ranging from 5300° K to 2800° K. Observers were given a simple questionnaire in which they stated for each different colour temperature whether the colour balance of the film was too blue, correct or too orange-red. The order of showing with the different colour temperatures was random and unknown to the observers. The results were evaluated as follows:

Criterion	Score
Too blue (cold)	−1
Correct	0
Too red (warm)	+1

A graph representing the results is shown in Fig. 1. The best straight line was determined by standard statistical methods and is shown in Fig. 1. The colour-balance point is given by a score of zero and occurs at 281 mireds or 3560° K. The mean value of the six colour temperatures used in this experiment is 273 mireds or 3670° K.

2.3. 35 mm Technicolor and Eastman Colour Test.

This test was done with two reels of Eastman colour 35 mm film and one reel of Technicolor 35 mm film. Successive one-minute excerpts from each film were shown with ten different colour temperatures (making thirty one-minute showings in all). The method adopted was very similar to that described in Section 2.2 except that five categories were permitted for the answers. These were scored as follows:

Category	Score
Much too blue	-2
Slightly blue	-1
Correct	0
Slightly orange	1
Much too orange	2

An analysis of the results for each reel shows no very distinctive features and the combined results are shown here as Fig. 2. This gives a colour-balance point of 210 mireds or 4750° K. The "spread" in the points in Fig. 2 is not surprising in view of the fact that the material upon which the judgments were being made was continuously changing and the film itself exhibits some changes of colour balance when being projected at constant colour temperature. Nevertheless there would seem to be little doubt about the judgments of the observers closely correlating with the changes in colour temperature of light source (correlation coefficient = 0·912 for Fig. 2). The range of colour temperature used in this experiment was 11 500° K to 2900° K with a mean value of 202 mireds or 4950° K. It is of interest to note that in this test, the experimentally determined colour-balance point and also the mean of the range of colour temperatures is much higher than for the 16 mm Kodachrome test.

2.4. Colour-Balance Tests on Static Colour Transparencies.

Three Kodachrome transparencies, three Ilford colour transparencies and three motion picture static frames (two Technicolor and one Eastman colour) were used. Each transparency was shown with ten different colour temperatures. The ninety combinations of picture and colour temperature of illuminants were shown to the observers in a random order in three sessions (to attempt to include all the combinations in one session would have fatigued the observers). Fig. 3 shows the results for the Eastman colour picture and is typical of the sort of result obtained with all the transparencies. Table 1 summarizes the results for all the nine transparencies.

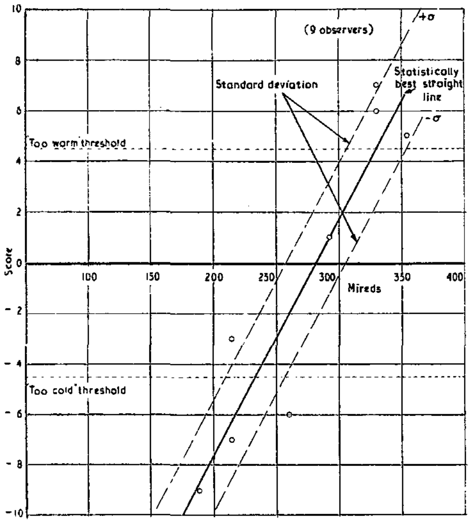

Fig. 1 - 16 mm Kodachrome test

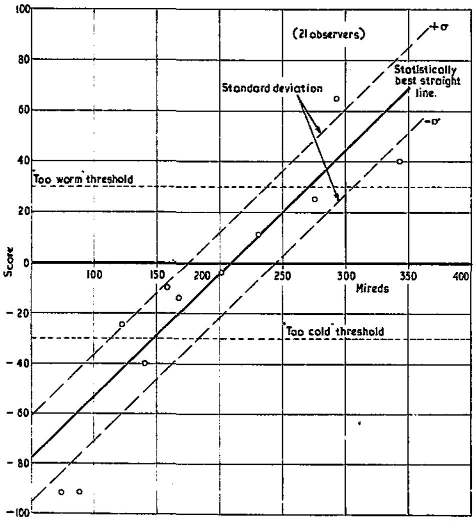

Fig. 2 - 35 mm motion picture test; combined results

TABLE 1

SUMMARY OF RESULTS

Picture No.	Description	Make	Preferred Value of C.T. of Light Source for Viewing (°K)		Limits of Probable Error (+ Twice Standard Deviation) (°K)	Limits of Tolerance	
						Warm	Cool
1	Flowerbeds	Ilford	3010	3360	2960 - 3070	2710	3390
2	Riverside		3500		3380 - 3620	3130	3950
3	House in Lawns		3560		3420 - 3690	3160	4070
4	Lawns	Kodak	3140	3360	3100 - 3190	2810	3560
5	Portrait		3570		3500 - 3640	3080	4270
6	Flowerbeds		3360		3280 - 3450	3920	3810
7	Two Ladies	Technicolor	3070	3450	3030 - 3120	2760	3440
8	Kitchen		3820		3790 - 3850	3360	4250
9	Office	Eastman	3230	3230	3190 - 3260	2880	3680
	Mean Averages:		3360		3290 - 3430	2980	3820

Standard Deviation of Preferred Values from the Mean Average = 250° K.
All values quoted to three significant figures.

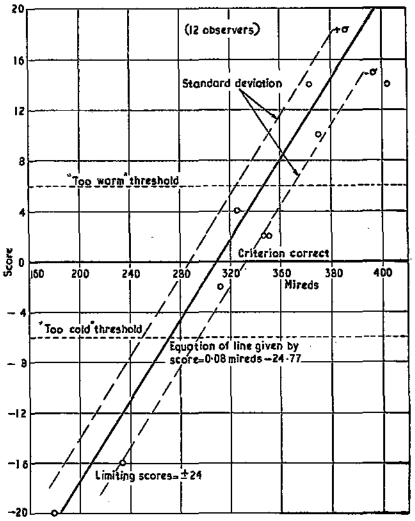

Fig. 3 - Eastman colour picture test

Certain interesting conclusions can be drawn from Table 1. The preferred value of colour temperature for viewing Ilford colour and Kodachrome transparencies is seen to be the same. This is perhaps not very surprising as they are both designed to be viewed in tungsten lighting. What is surprising is that Technicolor and Eastman colour static frames of film give results which are little different from Ilford colour and Kodachrome. These professional 35 mm motion picture materials are designed to be viewed in carbon arc light (approximately 6000° K). Further, the tests described in Section 2.3 gave a result of nearly 5000° K for professional motion picture film. The mean colour temperature of the ten values used in this experiment was 323 mireds or 3100° K.

3. COMPARISON OF THE FOUR EXPERIMENTS.

With the exception of the first experiment which used a blank field which was white, or near white, the remainder of the experiments have used static or moving colour pictures and have used similar naming techniques coupled with a randomised order of presentation of the different colour temperatures of illuminants. The ranges of colour temperature have not been the same in each experiment since different types of colour film material are "designed" to be projected at different colour temperatures and the original intention of each experiment was to find out how near to the nominal value was the experimentally determined one. It would appear, however, that the range of colour temperatures used in any one experiment has a considerable influence on the white point or balance point chosen. This is illustrated in Fig. 4 where the preferred white point or colour-balance point is plotted against the mean value. The best straight line connecting the four white points chosen in the various experiments is seen to cross-over the 45° line at an acute angle (of about $7\frac{1}{2}^\circ$). To a first approximation, the preferred white point is roughly the same as the mean value of the colour temperatures used in a given experiment. This is not quite true and for a low mean colour temperature the preferred value is in fact somewhat higher than the mean. Likewise for a high mean colour temperature, the preferred value is slightly lower than the mean. This would suggest that there is an optimum point where the two coincide. To determine this point with good accuracy would be difficult since the human eye is clearly very tolerant about colour-balance points and will adapt itself over a wide range given the necessary time to make the adaptation. (This is usually a matter of less than a minute). The present set of experiments gives an optimum at 239 mireds or 4190° K, but this value is subject to considerable experimental error. Statistical treatment of the results gives a range of 5100° K to 3560° K corresponding to ± standard deviation. If it were important to find this optimum white point with greater accuracy, a series of experiments using static colour transparencies and a number of different ranges of colour temperatures would be required. Motion picture film is not suitable owing to its variability and to the troublesome procedure of repeatedly replaying a given one-minute extract from a 1000-ft reel of film. It is not considered that the present set of experiments have ascertained the optimum white point with great accuracy but they have demonstrated the existence of an optimum.

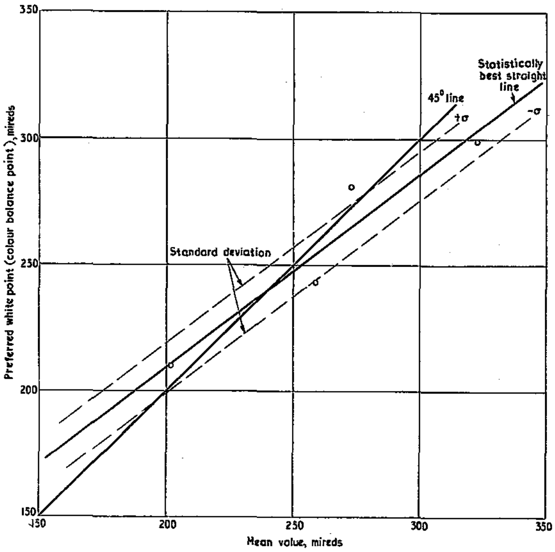

Fig. 4 - Preferred white point versus mean value for 4 experiments

I.G. Priest[2] found that the most acceptable white had a colour temperature of 5200° K, although the range over which an observer would accept a white under suitable adaptation conditions varies from 2800° K to 10 000° K[3]. We would not regard these results as disagreeing with Priest's and are prepared to accept his figure of approximately 5000° K.

4. CONCLUSIONS.

i. Although there is an optimum colour temperature for simulating white, observers are very non-critical about whites (providing they lie on the black-body locus) and will accept a wide range of colour temperatures as white.

ii. Illuminant C (6500° K) is certainly more blue than the optimum white but is in general a perfectly acceptable white. Nevertheless there is no special colorimetric reason for selecting it as a white point for colour television.*[4]

iii. Most types of colour film project satisfactorily over a range of colour temperatures which extends from tungsten lighting (3000° K) to carbon arc lighting (6000° K). If a single experiment is designed to find the optimum balance point for any given type of colour film, it will almost certainly give a result close to the average value of the colour temperatures displayed, irrespective of the type of colour film.

iv. This report applies to colour film or colour television pictures being viewed with little or no ambient lighting. If ambient light is present, the results of a previous report[1] still hold. Under conditions of tungsten ambient lighting, there is a stronger argument against Illuminant C as a standard white for colour television in that its blueness will be much more apparent.

5. REFERENCES.

1. B.B.C. Research Department Report No. T-045, W.N. Sproson, B.B.C. Quarterly, Vol. 8, No. 3, page 176, 1953.

2. I.G. Priest, Journ. Opt. Soc. of America, 5, 205-209, 1921.

3. R.M. Evans and W.L. Brewer, J. Soc. Mot. Pic. Tel. Eng., Vol. 63, page 5, July 1954.

4. B.B.C. Research Department Report No. T-054, Appendix 3.

6. ACKNOWLEDGMENT.

The experiment described in Section 2.4 was undertaken by Dr. Gilbert formerly a member of the B.B.C. Research Department.

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*It would appear that Illuminant C was chosen for the N.T.S.C. system of colour television adopted in the U.S.A., in the interests of reverse compatibility so that the monochrome picture produced on a colour receiver is similar in colour temperature to that of current black-and-white tubes.